AFRL-RW-EG-TP-2014-003



Damage-Sensitivity Correlations in Explosives

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Interim Report

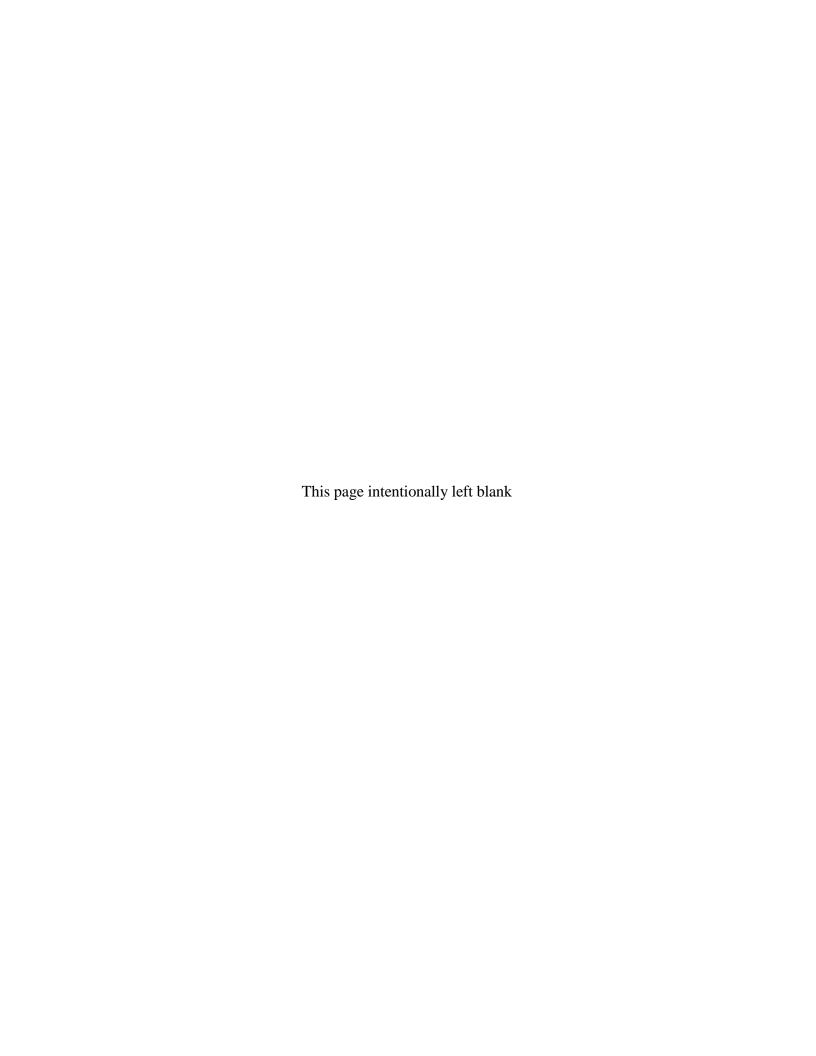
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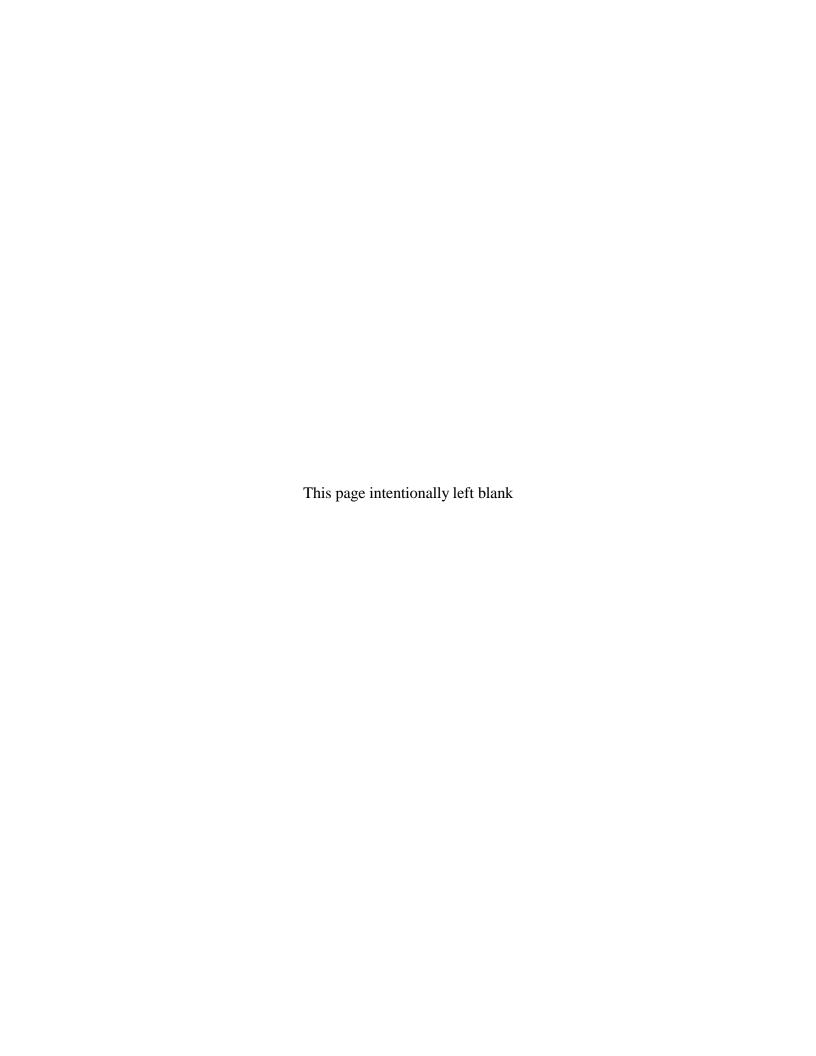
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14. ABSTRACT

As energetic materials are subjected to increasingly extreme environments, the effects of damage on changes in sensitivity at a fundamental level need to be better understood. To that end, a variety of experiments have been conducted on a plastic-bonded explosive. Shock Wave Apparatus (SWA) and Modified Gap Tests (MGT) were conducted based on similar tests performed at Gesellschaft für verteidigungstechnische Wirksysteme (TDW). X-Ray Computed Microtomography (XCMT) was conducted on the damaged explosive and the results analyzed using a MATLAB routine which quantified damage in the samples. In addition, a series of confined Split-Hopkinson Pressure Bar (SHPB) tests have been performed on an explosive simulant to understand the effects of confinement on the polymer binder and simulant, as the polymer binder exhibits substantial pressure sensitivity. SWA and MGT results suggest that damage increases sensitivity for initiation pressures below 3.5 GPa, while for pressures above 3.5 GPa the sensitivity of the explosive remains largely unchanged. Results from quantification of the XCMT images show that the distribution of void size appears to be the primary difference between the damaged and pristine explosive. Results from the confined SHPB tests show an increase in the true stress from about 3 MPa (unconfined) to 50-80 MPa (aluminum confinement) on the simulant at strain rates of about 500/s; aluminum confinement of the binder increases the stresses achieved from approximately 1 MPa (unconfined) to in excess of 80 MPa. The increase in stress is

accompanied by the introduction of axial cracking (similar to ceramics) as a failure mechanism

15. SUBJECT TERMS

Damage, pressure-sensitivity, strain rate-sensitivity, Split-Hopkinson Pressure Bar, explosive sensitivity

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Damage-Sensitivity Correlations in Explosives

15 October 2013

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Chad Rumchik, Jennifer
Jordan, John Cox
Energetic Materials Branch
Air Force Research Laboratory





Overview



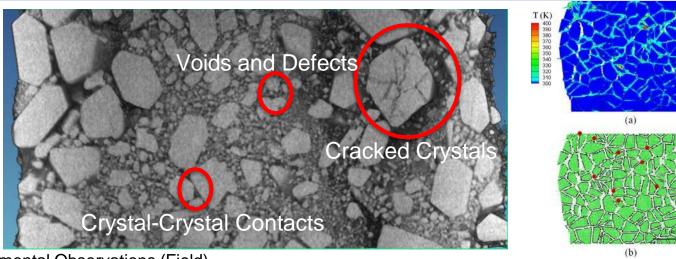
- Basic Principles: Damage in Explosives
- Experiments
 - Split-Hopkinson Pressure Bar
 - Shock Wave Apparatus
 - Modified Gap Test
- Non-destructive Imaging of Explosive
- Damage Quantification Methods
- Future Work





Composite Explosive





- Experimental Observations (Field)
 - "Adiabatic compression of trapped gas spaces"
 - "Other mechanisms involving cavity collapse such as viscous or plastic heating of the surrounding matrix material"
 - "Friction between sliding or impacting surfaces, or between explosive crystals and/or grit particles in an explosive"
 - "Localized adiabatic shear of the material during mechanical failure"
- Mesoscale Simulations (Barua)
 - Strong dependence on volume fraction of particulates
 - Viscoelastic dissipation in binder →temperature rise
 - Grain-matrix debonding, binder tearing → damage
 - Grain-grain contact → fracture and frictional dissipation

A. Barua, Y. Horie, and M. Zhou, "Energy Localization in HMX-Estane polymer-bonded explosives during impact loading," *Journal of Applied Physics*, **111**, 054902 (2012)

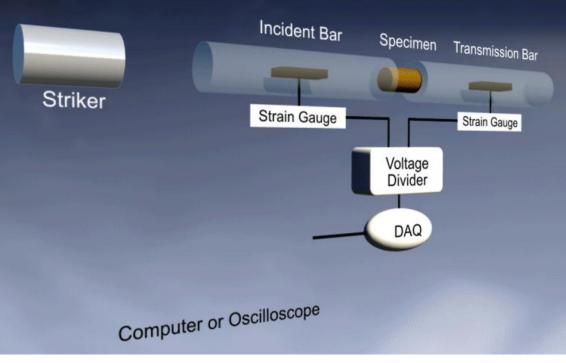
J.É. Field, "Hot Spot Ignition Mechanisms for Explosives," Accounts of Chemical Research, 25, 489-496 (1992).











- Use of confining ring to apply pressure
 - PMMA (1/8" thick)
 - Aluminum (1/4" thick)





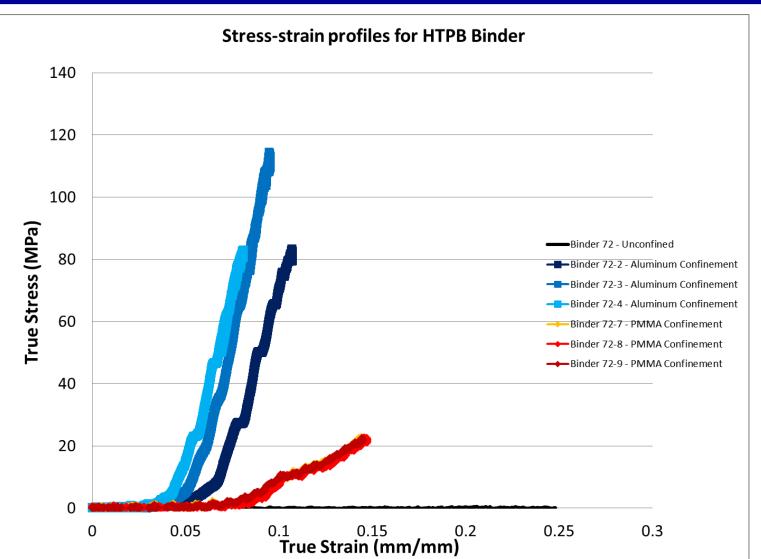


- Use of confining ring to apply pressure
 - PMMA, aluminum
 - Mandates the use of samples with same diameter as bars (19 mm)









Strain-rate of all samples about 750/s, except for unconfined (black), at 1250/s

Estimated radial stresses:

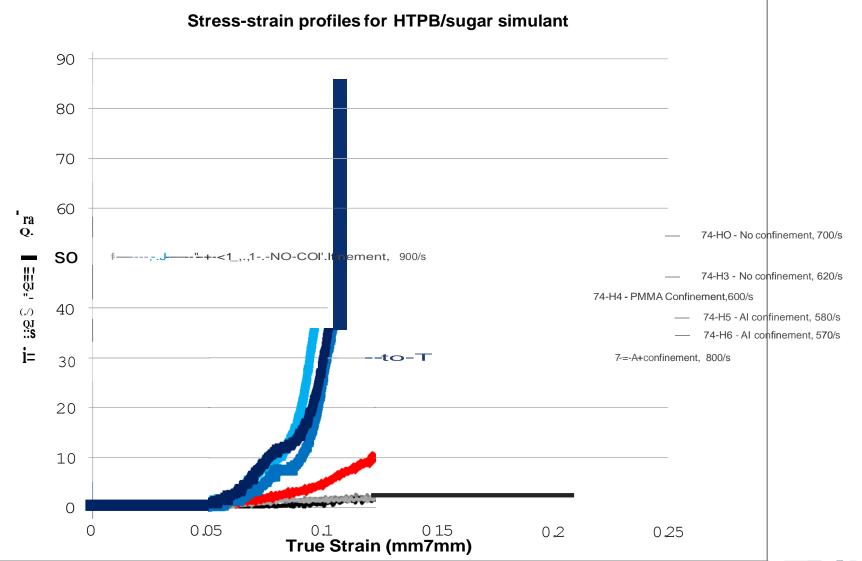
Al: 20 MPa

PMMA: 2 MPa







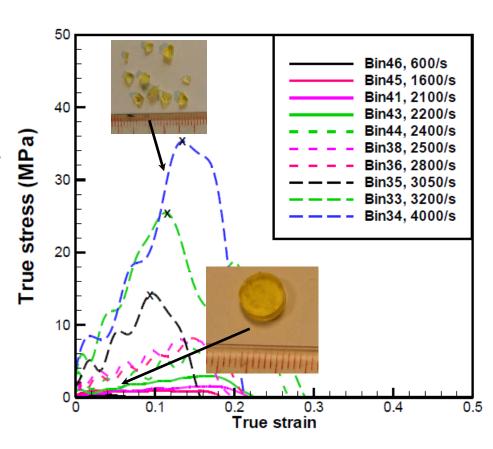








- Samples after testing
 - Largely go back to their original cylindrical shape
 - Some damage previously seen in binder at highest strain-rates (3000/s)
 - Strong rate and pressure sensitivity

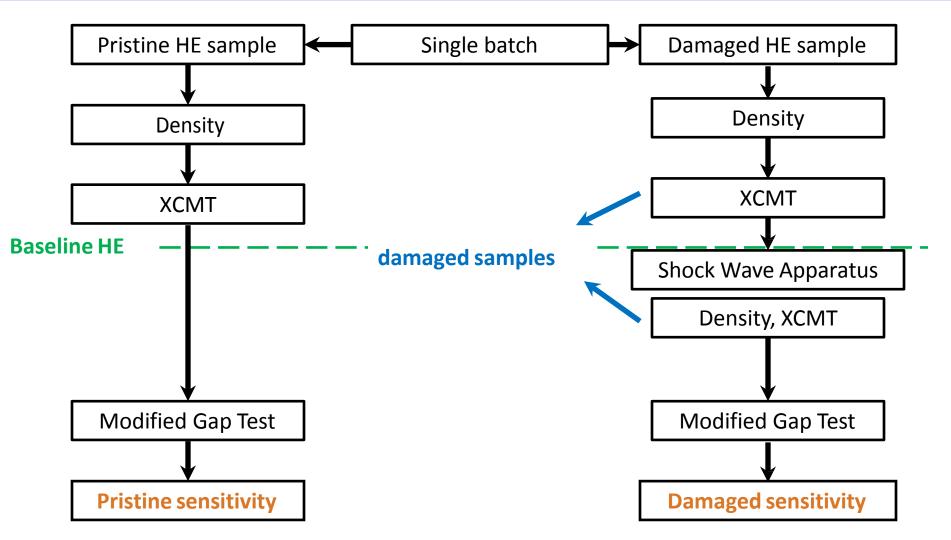






Ideal Testing Process

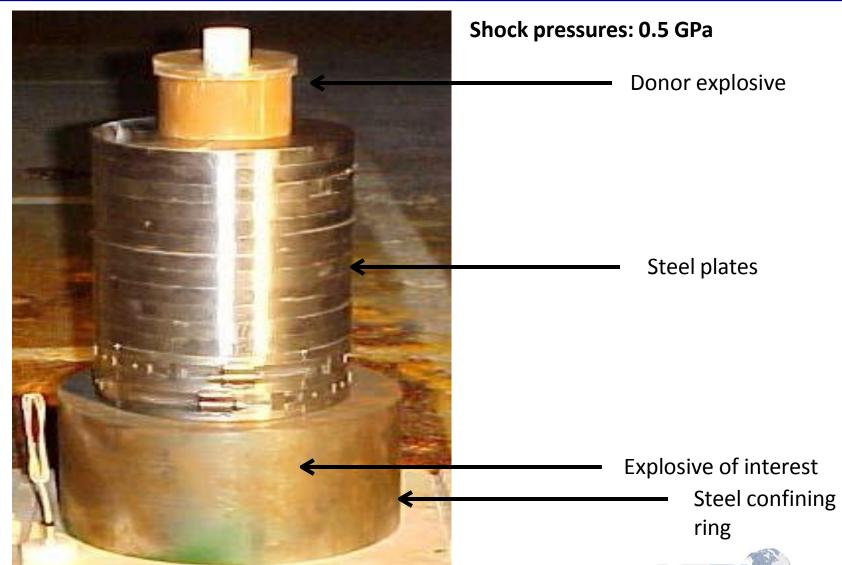






Shock Wave Apparatus

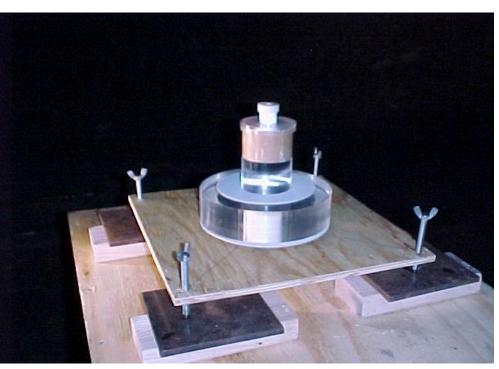




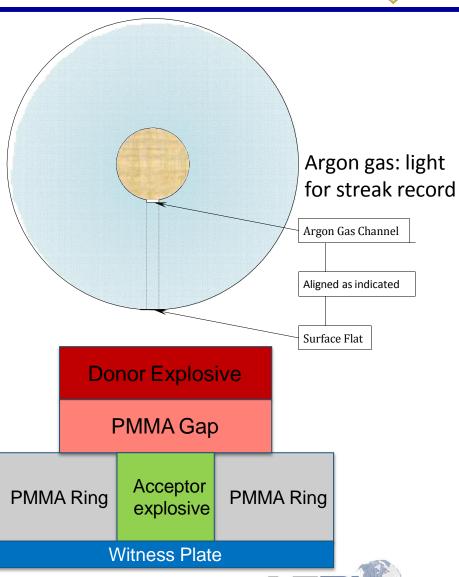


Modified Gap Test





- Assumption
 - Run-to-detonation (RTD) on outside is representative of RTD in interior of charge

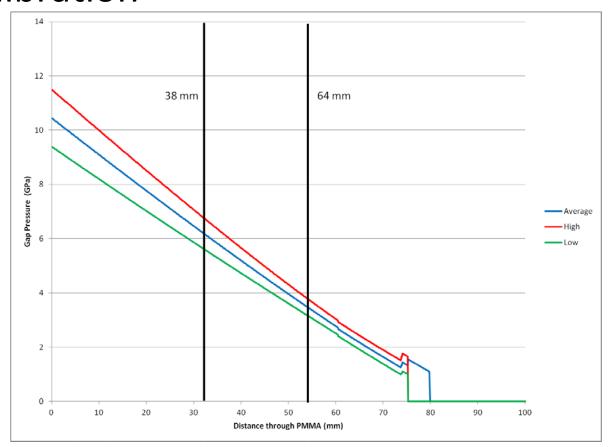




Modified Gap Test



Calibration



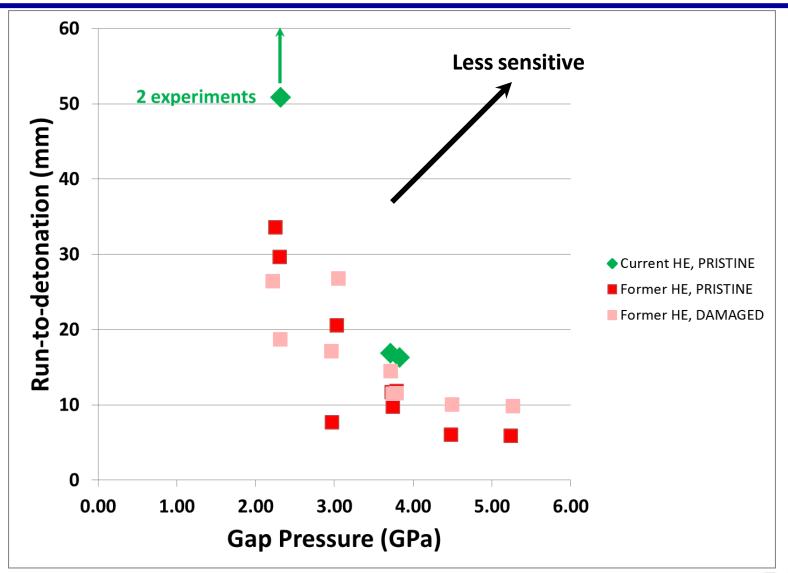
Errors in calibration are about 10% for normal PMMA gaps (38-64 mm)





Sensitivity of Explosive







Sensitivity of Explosive



- Current HE appears to be less sensitive
- Differences most prominent at lower pressures
 - Negligible differences between pristine and damaged at higher pressures
 - Uncertainty of 2 mm in RTD
- Some scatter in the data



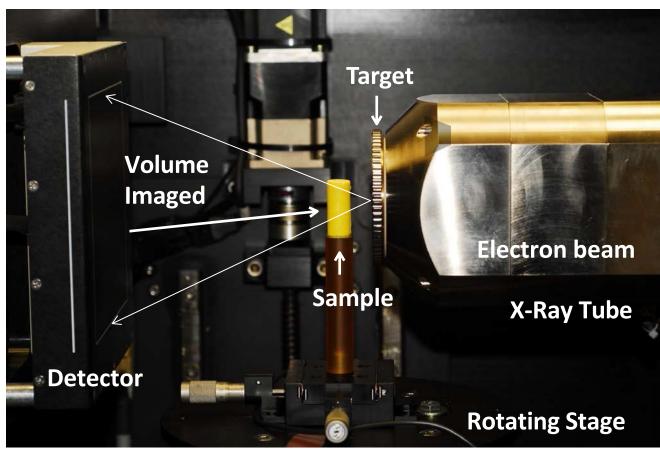


XCMT Imaging





 Pristine PBX for current study, relatively free of voids (grey circles)



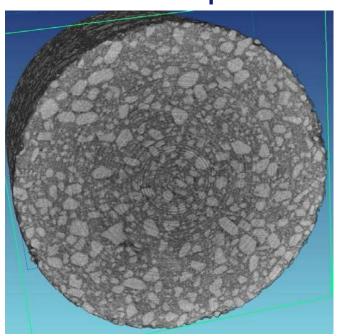




Damage of Explosive



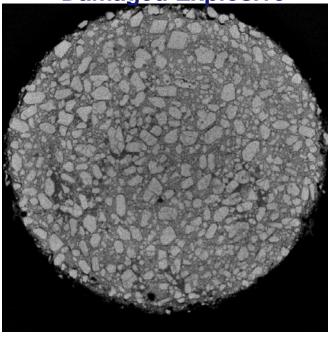
As Processed Explosive



0.5-inch diameter core Target: Al 50kV, 178 μA 0.5 fps, 5 frames/view 720 views

Explosive loading at ~0.5 GPa

Damaged Explosive



0.5-inch diameter core
Target: W/diamond 45kV, 300 μA
1 fps, 2 frames/view
1440 views

Test sample is 2" in diameter. XCMT sample is cored from test sample.

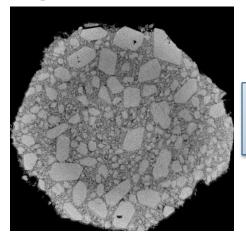




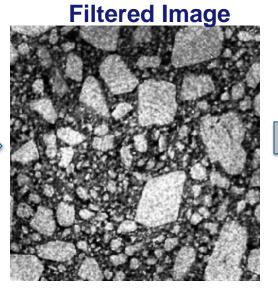
Analysis of XCMT Images

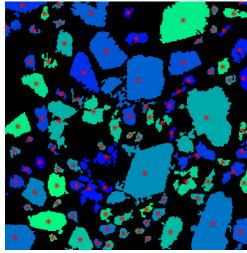


Original Microstructure

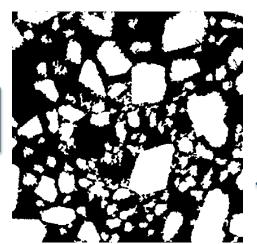


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Particle Statistics



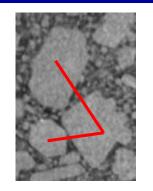
Convert to Binary

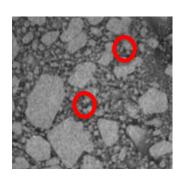


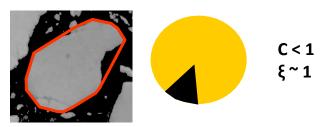
Key particle statistics

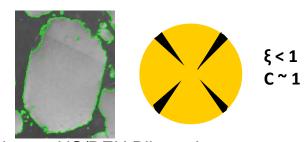


- Particle size distribution
- Spacing between grains
- Void volume fraction
- Void size distribution
- Convexity by perimeter/area









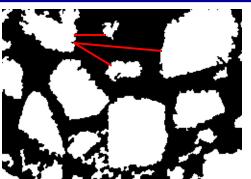
W.A. Arnold, "TDW Lessons Learned and Status 2011," Presentation at US/DEU Bilateral Workshop, October 2011.

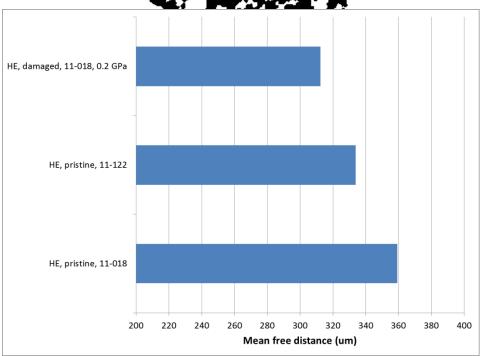




Mean Free Distance







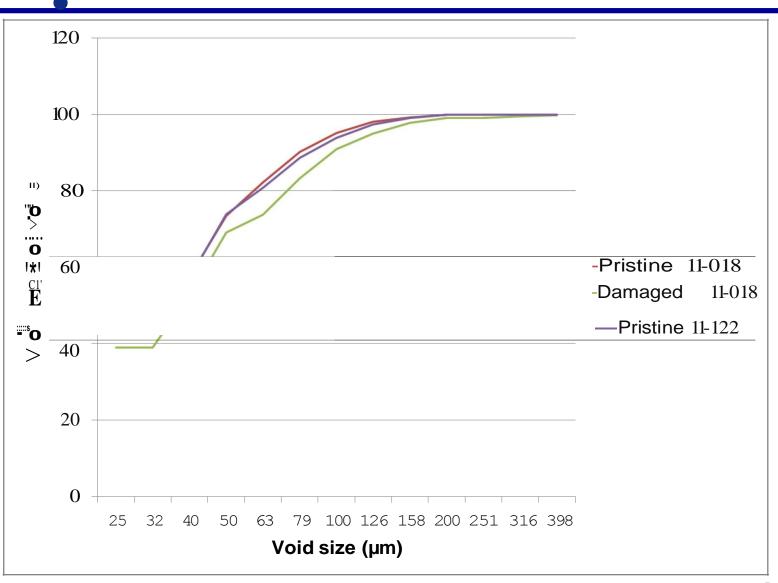
- Distance between particle boundaries through matrix
- Captures distance between particles indicative of regions of friction or sliding and hot spot generation
- Particles in new batch of explosive and damaged explosive are closer together than in original batch

E.E. Underwood, Quantitative Stereology, Reading, MA: Addison-Wesley Publishing Company, p. 82-83 (1970).



Void Size Distribution







Future Work



- Compare pristine, damaged simulant samples
- Confined SHPB experiments on HE
 - Determine change in microstructural metrics
- Complete Modified Gap Tests on new HE
 - Shock Wave Apparatus experiments completed





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